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14. ABSTRACT
Progress report on the implementation of a test bed based on MRLife prediction code. This demonstration will be extended to a Navy consortium within a state space for regional collaboration, whose progress is described.

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Contract Data Requirement Progress Report, 270 days
Contract No. N00014-99-1-0158
NAVCIITI
Dr. Kenneth L. Reifsnider

Data Item No.: 0018: Test Bed Demonstration using MRLife

This program element is about 50 percent complete. The PI for this task was on sabbatical in the first six months of the subject program. Delivery of the item is expected in the early Spring of 2000. Progress on the task includes the following:

1. A consortium of users for an existing engineering code developed by the investigator has been constructed. It includes Pratt & Whitney, Owens Corning, United Technologies, Allied Signal Composites, Oak Ridge National Laboratory, Goodyear, Johnson and Johnson, Westinghouse, and Allison.
2. Methodologies for information exchange and collaboration in that consortium have been constructed and are being evaluated. A recent evaluation of the "virtual school" software being developed in part by another NAVCIITI investigator suggests that the next phase of the present effort should concentrate on constructing the hardware link to a select sub-group of the consortium members for trial of the hardware and software needed to conduct these trials.
3. A consortium member from Germany (University of Kaiserslautern) is being added to the consortium, to add the element of international information exchange to the methodology. The PI on this task visited that laboratory on June 5, 1999 to construct the details of their involvement. A proposal for auxiliary funding to support the efforts of that laboratory in the conduct of their part of this task has been submitted to the **NSF.** Interaction (exchange of personnel) of the two laboratories is underway.
4. The description for the staff position to support this task has been approved by the University. A prospective candidate for that position has been hired, and begins work on 1 September, 1999.

The follow-on to this work will concentrate on establishing a consortium of Navy users. There are some 84 existing Navy contracts at Virginia Tech, and new Naval partners are being added as a result of the NAVCIITI program. From this group, we will establish a consortium of Naval Laboratories and installations that have a direct and active interest in the results of NAVCIITI and our IT work in general. This work has already begun in many ways. We have liaison with NSWC Carderock Naval base, and have visited their laboratory with a multi-investigator group to discuss cooperation and interaction, including implementation in fleet operations. We have laid the groundwork for signing an MOU with that lab, with a focus on three areas; structural composites for topside application including antennas, embedded sensors, and fire-resistant communication structures. The network technology established in task 1 will be used to bring together and define a consortium in this task. Moreover, the NAVCIITI framework will be used as the mechanism to define collaborative goals and objectives for that consortium. This will extend the collaboration from our campus to the Naval community, in the specific areas of interest to our Naval partners. This consortium will also be a key to the

implementation of technology developed by the NAVCIITI effort, and will provide guidance and direction to the collective program.

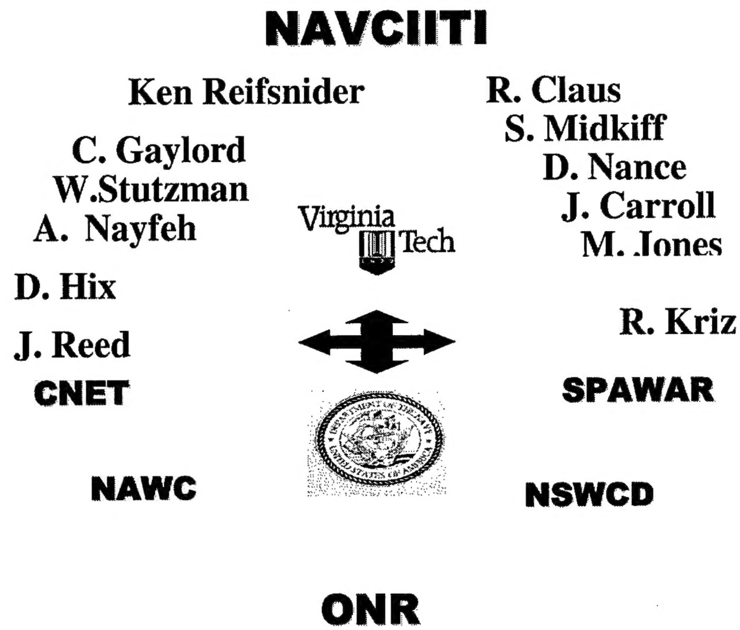

Figure 1 Diagram of interacting entities for NAVCIITI (partial listing).

Data Item #0020: Definition of a State Space for Regional Collaborative Consortium

This is a cooperative task with item no. 0018, and is, therefore, also behind schedule for the reasons discussed in that progress report. However, considerable fundamental work has been done on the issue of the basic nature of a state space.

The fundamental problem addressed is the question of defining a state space that can be shared by a network-centric consortium in such a way that decisions can be made in real time by all participants with a minimum of collateral message exchange. The sophistication and effectiveness of the state space is measured in part by the degree to which all participants can use the information it provides to perform their assigned tasks without question-answer communication with the other participants.

The approach we have taken to this problem is engineering based. It is based on the following canons:

- Canonical data are collected (in real time) by the state space model. This is not a simple step. Canonical data (independent measureables that uniquely define the state

of the situation) must first be identified. Sampling methods (intelligence) must be constructed and secured. Information from the sampling equipment must be identified and correlated, and the results presented to the model with a minimum of latency.

- The canonical data are used as inputs to an interpretative model to generate information, i.e., at this point the data have a meaning in the context of the situation space involved.
- Each information input is related to the other available inputs by the model so that the collective meaning of the information is determined, i.e., the information becomes knowledge.
- Finally, and most important, the best available philosophy generated off-line by the best experts and research teams is incorporated in the model to interpret the knowledge to present a predicted result, i.e., intelligence.
- It is the basic premise of the present approach that the preferred state space for a regional consortium, especially if the shared enterprise is a dynamic combination of events, is a rendering of the expected result of all of the data inputs and the instantaneous decision space of each and all of the participants.

Two experiments were conducted to test some of these canons. Only one will be summarized here; the other is not yet complete. We chose to test the influence of real-time inputs on the accuracy of the expected result (predictions) of a well established model with known validity. The situation involved was damage accumulation in semi-brittle composite materials. The analogue with the subject state space is rather strong. Damage development in composites is stochastic. However, properties of the composites change because of the statistical accumulation of events, not because of the statistical occurrence of those events. This is essentially identical to the situation in a battle theater, such as a littoral battle space. The basic question was, in such a situation, if one can collect analogue information in real time, is the prediction of the expected result substantially better? It should be emphasized that the parameter being sampled is related to the predicted result indirectly, i.e., the result to be predicted is not being sampled.

In the present case, the information sampled was stiffness change of composite specimens under cyclic (fatigue) loading. Stiffness change can be related to changes in internal stress distribution in the interior of the specimens using micromechanical models, to get information from the data. The nature of that information can be interpreted with mechanics of materials to determine why the stiffness change is occurring, to obtain knowledge about the process producing the change. In the current experiments, this amounted to interpreting the information with mechanics to determine if the stiffness change was being caused by matrix cracking or fiber fracture.

Finally, that knowledge was used in a well established model of damage accumulation, called the critical element philosophy (developed by the author at Virginia Tech) to predict the remaining strength and life of the *individual* specimens tested. This last point is critical. The essence of the present approach is that statistical information about a fundamentally statistical (stochastic in this case) collection of events is being used to

predict the *specific* result of an *individual* embodiment of those events, i.e., the present situation. This is a great step forward. Generally, models predict the expected average result of a sample of embodiments, i.e., several occurrences of the sequence of events. That is not useful in the case of battle management. It is of little use to be able to say, "if this set of events and circumstances were to occur 100 times, the expected result would be the following 90 percent of the time with 95 percent confidence – the usual statistical reliability statement. What sets the battle space problem apart is that a specific answer for the situation at hand is essential; an average prediction will not win the day.

What makes the specific prediction possible is the collection of a canonical data stream that guides the model for a specific situation. For the composite analogue experiments, that canonical data was stiffness change. The interpretive critical element model was implemented using the MRLife™ code developed by the Materials Response Group at Virginia Tech. A few references to the details of that code are listed below.

The results of the experiments will appear in the International Journal of Fatigue. An example of the results is shown in Fig. 1 below.

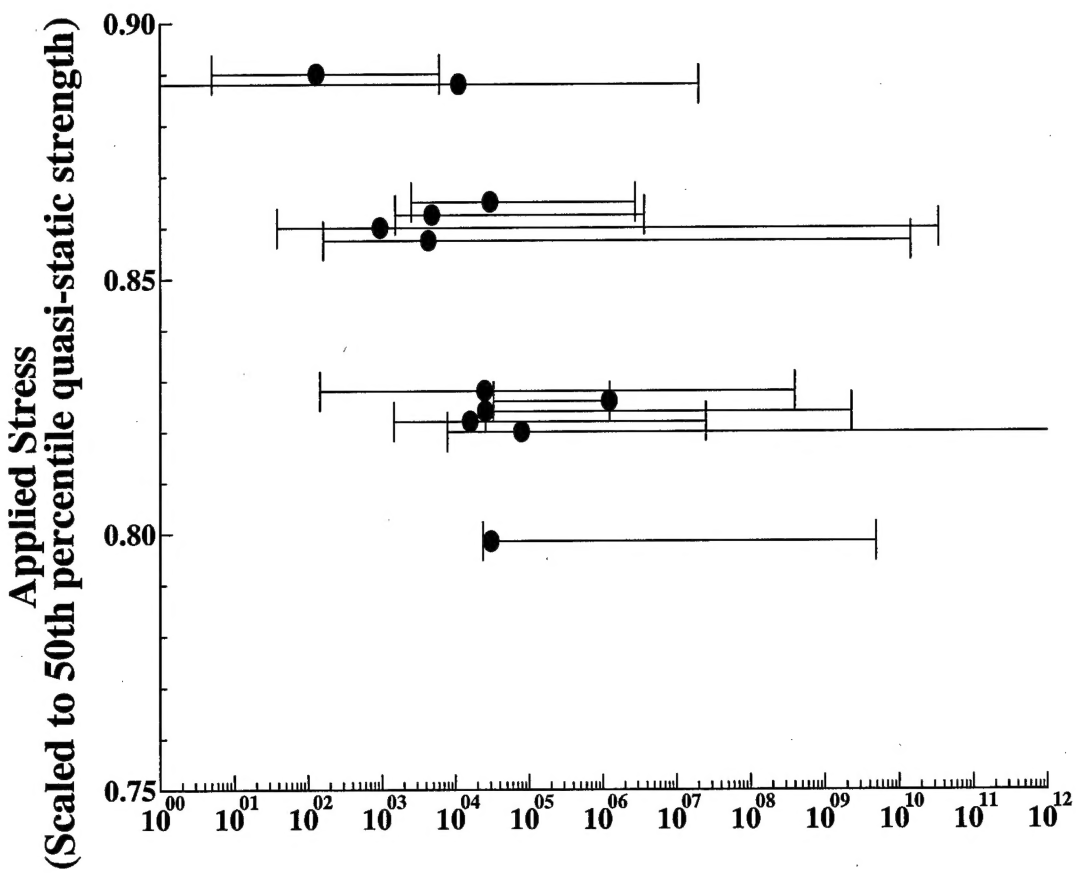

Figure 1 Predicted (10-90 bounds indicated by bars) and observed data (dots) for the life of cross-ply laminates using real-time stiffness change to make model predictions specimen specific.

The figure shows essentially four applied conditions, at normalized nominal applied stress levels of 0.89, 0.86, 0.83, and 0.8. Within the 0.89 group, for example, the experimental data differ by two orders of magnitude! But the data fall nearly in the middle of the model predictions for those two specific tests. Similar results are seen in the other groups.

While much is yet to be done on this approach, the results of this part of the effort strongly support the basic premises of the concept. So far, we have learned that by carefully selecting canonical input data to sample in real time, and by using well established representations of the behavior of the system of many variables and events, on the average, it is possible to predict with exceptional accuracy the specific result for one sequence (or embodiment) of those events, i.e., the present case. For the present problem at hand, the results suggest that the results of a specific battle space can be predicted, instantaneously in real time, with excellent accuracy for that specific set of events, by this approach. Continued investigation is needed to verify this result, and to thoroughly test the rest of the features of the approach. Field testing of the approach is recommended.

To that end, we have visited the NSWC Carderock to discuss interaction and implementation of some of the NAVCIITI results. Efforts are underway to construct an MOU to effect such implementations. Several target programs for implementation have been identified. We have also had discussions with Newport News Shipbuilding and Martin Marietta with the intent of bringing NAVCIITI results to the CVN77 carrier program.